This manuscript's first original version was submitted on April 29th, 2023, for consideration in the peer-reviewed Applied Energy journal. Please note that the manuscript has not undergone peer review yet and has not been formally accepted for publication. Subsequent versions of this manuscript may have different contents. Please feel free to contact the corresponding authors. We welcome feedback.

Agrivoltaic systems potentials in Sweden: a geospatial-assisted multi-criteria analysis

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Abstract

Agrivoltaic systems represent an intelligent solution combining electricity production from solar photovoltaic technology with agricultural production and avoiding land use conflicts. Geographic Information System technologies can support the implementation and spread of agrivoltaic systems by identifying the most suitable areas using useful spatially explicit information concerning techno-agro-socio-economic criteria.

In this study, we have developed a procedure to identify and classify suitable areas for agrivoltaic systems in Sweden. An Ordinal Priority Approach based multi-criteria decision making algorithm is established to calculate the weights of the selected evaluation criteria through expert interviews. The land use data refers to the Corine Land Cover 2018 product.

The results show that 8.55% of the Swedish territory, approximately 38,485 km^2, is suitable for installing APV systems. Among this area, 0.17% is classified as "excellent", about 15% as "very good", about 72% as "good", about 13.1% as "moderate", and less than 0.1% as "poor". Through the deployment of vertically mounted agrivoltaic systems with bifacial photovoltaic modules, the total "excellent" areas can potentially supply 2.44 TWh against the electricity consumption in 2021 of about 143 TWh. On the other hand, the land classified as "excellent" and "very good" could potentially provide about 207 TWh, which is a much higher production capacity than the 2021 electricity consumption. The total potential installed capacity for "excellent" areas is 2.3 GW$_p$, while for areas classified "excellent" and "very good" is 201 GW$_p$.

1 Introduction

Agrivoltaic (APV) systems represent a smart solution to integrate agricultural activities and electricity production on the same avoiding conflicts land between the Sustainable Development Goals (SDGs) (Campana et al., 2021). This dual use of land is achieved by using special supporting structures, such as interspace or overhead structures (Gorjian et al., 2022). This technology has a direct impact on energy, food, the environment, the economy, and society (Kumpanalaisatit et al., 2022). Solar energy, as a renewable energy source, is exponentially expanding and land is needed for its development. APV systems not only can minimize the land use conflict between solar power and agricultural production but also increase food security. The environmental impact of APV systems, in terms of greenhouse gas (GHG) emissions, could also be reduced if compared to traditional agricultural practices because of different microclimate conditions (Cho et al., 2020). Furthermore, APV systems may generate an extra income stream for the farmer (apart from selling agricultural products) by selling the electricity produced by solar panels (Guerrero and Ramos, 2021). For society, APV systems have the potential to increase self-sufficiency in food and energy in remote and arid areas, while improving the communities' environments by using less fossil-fuel-based machinery (Irie et al., 2019; Agostini et al., 2021). Retrofitting ground-mounted PV systems into dual-purpose agricultural and electricity production is another possibility to boost APV systems deployment. However, further research is needed to ensure a proper transition and efficient adoption of agricultural activities under existing PV systems. Specifically, a mathematical model to predict the retrofitted APV system, a better understanding of crop performance under PV systems, and appropriate APV policies to incentivize the adoption but at the same time avoid the loss of agricultural land (Kumpanalaisatit et al., 2022). The estimated global APV market size in 2021 was 3.17 billion USD and it is forecasted to reach 8.9 billion USD by 2030 (Precedence Research, 2023).

Several works have been focusing on estimating the potential of APV systems in different regions of the world using different approaches. Pearce and Dinesh (2016) performed a simulation study using PVSyst® for PV production and STICS crop model for agricultural production. The results provided an increase of over 30% in economic value (solar electricity generation with shade-tolerant crop production) for farms deploying APV systems instead of traditional agriculture. Particularly, for the USA, if lettuce cultivation alone is converted into APV systems, the increased capacity of PV systems would be between over 40 to 70 GW. The study stressed that further research and development are needed for different crops and geographic areas to be able to evaluate the potential of APV systems in the world. A study in Turkey (Coşgun, 2021) showed the mapping of solar energy potential in the country based on the solar radiation received monthly and yearly in terms of irradiance (kWh/m^2) and sunshine time. The study emphasized Turkey as being a top ten country for agricultural production in the world, making it appealing for the development of APV systems. The analysis to determine the potential of APV systems was performed in three cities, located in the north, middle, and south of the country. Nevertheless, the methodology was based on analysing the solar paths computed from PVSyst® and typical meteorological year (TMY) irradiation, leaving out many other important factors to consider, for instance, soil type. A study in the USA investigated the environmental performance of sheep based APV systems using an LCA approach (Handler and Pearce,2022). The authors highlighted that to accommodate the current entire country's domestic sheep in APV systems, the USA has the potential to expand utility-scale PV by a factor of four. The study showed that the reduced environmental impacts associated with producing food and electricity that APV systems offer in comparison to conventional ground-mounted PV are clear evidence to encourage sheep grazing on all appropriate conventional PV systems in the country. Current research on APVs primarily focuses on analysing microclimatic changes at specific locations (Armstrong et al., 2016; Hassanpour Adeh et al., 2018; Barron-Gafford et al., 2019; Amaducci et al., 2019). In Bangladesh, for instance, researchers have used the ORYZA2000 cropping model to estimate daily potential crop production in APVs with rice paddies (Ahmed et al., 2022). However, this method involves simulations conducted at specific sites and does not provide high spatial resolution. Another approach that provides a larger spatial scale has been demonstrated in a recent study by Cappari et al. (2021), who modelled four crops in Oregon and North Carolina using stochastically generated weather variables for APVs. The crop model employed regressions between local weather variables averaged over two-month periods and county- or state-level crop yield data.

Assessing the performance of APVs at specific locations can be achieved by using a land equivalent ratio (LER) to determine the relative area needed to produce the same amount of biomass and electricity with separated productions on different land surfaces when combined in APV systems. LER is a useful index for comparing different APV designs at a specific location. For instance, Valle et al. (2017) analysed solar tracking APVs and fixed stilted APVs with different PV densities and found that solar tracking solutions could achieve high productivity per land area unit compared to stationary PV panels in APV systems while maintaining similar biomass production of lettuce under full-sun conditions in Lavalette near Montpellier, France.

The LER can also be used as an index for geospatial assessment of APV systems. Willockx et al. (2022) utilized LER, levelized cost of electricity (LCOE), and electricity production as parameters to evaluate the potential of APVs in Europe. They used a gridded data set of 25km grid cells, where each cell has unique meteorological data representing median weather conditions and developed a typical meteorological year. However, the study conducted by Willockx et al. (2022) assumed that the open-field and APVs crop yield ratio is equal to one and do not include environmental effects.

The development of APV systems, or the use of solar panels within agricultural lands, holds significant promise for generating electricity without reducing land commitment or harming agriculture. The potential of this approach can be easily assessed using Geographical Information Systems (GIS) and multi-criteria decision making (MCDM) techniques. Despite in the recent years the research activities on APV systems have been increasing exponentially, few research activities have been conducted on using GIS techniques to find the most suitable or optimal areas for the implementation of APV systems. GIS techniques have reached a high level of maturity and have emerged as a powerful tool for the decision-making of spatial deployment of solar power plants. GIS can handle, process, and analyse large quantities of spatial data and is often used together with Multi-Criteria Decision Analysis for optimal site selection of PV plants (Charabi and Gastli, 2011; Lindberg et al., 2021). Criteria are used in a "Boolean overlay", which means that the GIS layers representing different properties of the studied geographical area are overlaid and sites or patches of land that meet all or an acceptable number of criteria are labelled as feasible or optimal (Choi et al. 2019). Lindberg et al. (2021) have recently published a utility-scale solar PV plants site selection guide combining GIS and power flow analysis with a case study based in Sweden but excluding agricultural land as feasible areas for installation. GIS common criteria for land suitability to build PV plants are ranked accordingly as: solar radiation incident on the land, proximity to the grid, slope of the ground, proximity to main roads, proximity to residential areas, and land use (Rediske et al. 2019). Although a similar GIS approach to conventional PV plants is expected also for APVs, more emphasis should be devoted to land-use and agronomic criteria to balance power generation targets while maintaining crop productivity. GIS-based site selection for APVs has been performed in few studies.

In a study conducted by Majumdar and Pasqualetti (2018), the potential of implementing APV systems in the Phoenix Metropolitan Statistical Area of the USA was evaluated using various parameters analysed with GIS. These included cultivated land, population density, residential energy needs, land cover change, solar energy potential, slope, aspect, shading effects at different panel

densities, crops grown in the area, and distance from transmission lines of varying voltages (ranging from 69 kV to 500 kV). As many parameters can be used to assess the potential of APV systems, it is essential to weigh their impact accurately to present a reliable evaluation of their potential at a given geographical location. To this end, Yamada, and Ogata (2021) conducted a potential evaluation of APV systems in Japan using GIS. They excluded farmland unsuitable for power generation and implemented a weighting system for each parameter, assigning a larger weight to parameters of greater importance. This weighting system can be used to determine the potential of APV systems relative to the parameters used. Jing et al. (2022) proposed a multi-disciplinary assessment framework to estimate the potential of urban rooftop APV systems by integrating GIS, biogeochemical simulation, and solar power simulation. GIS is used to identify suitable rooftops, classified based on their function and footprint. Further screening has been applied to rule out non-suitable rooftops: shading by neighbouring buildings, insufficient rooftop structural strength and already occupied rooftops. The framework has been assessed for urban rooftops in a city in China, Shenzhen. The results showed a potential of generating 1899 GWh/year of solar energy (fulfilling 0.2% of the whole city's electricity demand) with an installed capacity of 2,106 MW. On the agricultural production side, in this case, lettuce, the potential would be almost 10^6 tonnes/year, fulfilling the whole city's demand. On the other side, extra freshwater would be needed for irrigation. This is one of the first works using an integrated framework to assess the potential of APV systems in an urban context using GIS. Recently, Chatzipanagi et al. (2023) assessed the technical potentials of APV systems in Europe for different land area subcategories. The authors did not use a GIS approach but relied on Eurostat's statistical data and assumed different area coverage percentages and power-to-land area ratios. Assuming an average power-to-land area ratio of 0.6 MW/ha, the authors quantified that 0.77 % of the utilised agricultural area in the European Union is required to meet the target of the EU Solar Energy Strategy 2030 of installing approximately 730 GW_p by 2030, while 0.85 % of the utilised agricultural area is required to meet the 1 TW_p target.
To the best knowledge of the authors, no research activities have been conducted on assessing the suitable areas and suitable areas classification of APVs in Sweden to afterwards assess the potential of such systems in reaching the national renewable and electrification targets. Similar, extremely few studies can be found in literature for other parts of Europe or the world. The main research questions of this study are:

1) What are the suitable areas for installing APV systems in Sweden?
2) How can those be classified from excellent to poor?
3) What is the potential electricity supply and installed capacity from APV in Sweden?

This study is a first attempt to answer the above research questions through a developed GIS-MCDM approach. The reminder of the paper is structured as follows: Section 2 provide a comprehensive overview of how the suitable areas for installing APV system in Sweden are calculated by identifying the techno-agro-socio-economic criteria of interest, defining the restriction criteria, and assigning the weights for each evaluation criteria. Section 3 summarizes the results of the analysis and provides the potential of APV system in Sweden in terms of electricity supply compared to current and forecasted electricity demand in Sweden. Section 3 also discuss the achieved results within the national context. Section 4 summarizes the main outcome of the study.

2 Materials and Methods

To achieve the study purpose, a five-step GIS-MCDM approach, refined from Elkadeem et al. (2022), is developed as illustrated in Figure 1. The GIS is used to perform location-based analysis and real geographical data visualization and processing, while MCDM analysis is leveraged to integrate opinions given by experts regarding nexus assessment among conflicting criteria adopted for site suitability analysis of APV.

First, data corresponding to different techno-agro-socio-economic criteria of interest to find the optimal locations of APVs projects in Sweden are identified and collected. Table 1 shows the list of restriction criteria, while the suitability classifications of the evaluation criteria are summarized in Table 2. Further, the raw map of each criterion proceeds and is organized using ArcGIS Pro software processing tools are provided in Figure A1 in the Appendix.

Second, the constrained map reflecting the unsuitable areas for SPV implementation is derived by via Boolean overlay analysis considering the appropriate buffers specified in Table 1. This is accomplished according to the nature of the country's features, research objective, and opinions of experts. It is worth mentioning that the seasonal precipitation and potential evapotranspiration values, refer to the period April to September included, as also considered in the studies from Grusson et al. (2021) for irrigation of spring cereal, potatoes, and grass ley in Sweden. Morel et al. (2021) reported common sowing and harvest dates from barley, maize, oats, and spring wheat varying between the beginning of May to the begin of October. Concerning the restriction criteria on power grid infrastructures, it is somehow difficult to set a boundary due to the lack of high-resolution data of the distribution grid. For small-scale APV systems serving farms, we can assume that wherever there are the 5 classes of the land use defined in Table 1, it is very likely that there are points of connections to the grid (i.e., 10 kV grid) for small-scale APV systems (i.e., less than 1 MW_p). For larger PV and APV systems, the availability to high voltage power grid connection within 1-3 km (Air By Solar, 2022) is the most important feature for the PV parks. The data concerning power infrastructure can be found at Open Infrastructure Map (2022), ArcGIS Map Viewer (ArcGIS, 2022), or at Overpass turbo (2022). Nevertheless, the resolution does not allow to perform an in-depth analysis. Thus, the power grid buffer has not considered in this study as in Lindberg et al. (2021). For larger scale systems, more in details assessment should be carried out.

The **third** step according to the method chart given in Fig. 1, involves generating the suitability map for each evaluation criterion. To do so, each criterion layer is first converted to a raster format (pixels) and then reclassified to a common grade scale from poor suitable to excellent suitable as given in Table 2 using Spatial Analyst toolbox of ArcGIS Pro. This step allows for assigning a weighting score to each grid cell.

In the **Fourth** step, an Ordinal Priority Approach (OPA)-based MCDM algorithm (Ataei et al., 2020), which features robust accuracy results, and quick implementation is established to calculate the weights of the evaluation criteria. The step for OPA execution includes (Mahmoudi et al., 2021) (i) defining the criteria list; (ii) performing questionnaire analysis by specifying the expert panel, assigning rank for each expert, and collecting feedback from the experts regarding their ranking priority of criteria based on his/her view; (iii) solving the linear mathematical model of OPA as expressed in Eq. (1); (iv) calculating weights of each criterion using Eq. (2).

$$\begin{aligned} & \text{Max } \phi \\ \text{S.t:} \quad & \phi \leq i\left(j\left(k\left({W_{ijk}}^{r} - {W_{ijk}}^{r+1}\right)\right)\right) \quad \forall\, i,j,k \text{ and } r \\ & \phi \leq\ ijm\, W_{ijk}^{m} \quad \forall\, i,j \text{ and } k \\ & \sum_{i=1}^{p}\sum_{j=1}^{n}\sum_{k=1}^{m} W_{ij} = 1 \end{aligned} \tag{1}$$

$$W_{ijk} \geq 0 \qquad \forall\, i, j \text{ and } k$$

$$W_j = \sum_{i=1}^{p} \sum_{k=1}^{m} W_{ijk} \quad \forall j \tag{2}$$

where: ϕ is the objective function, J is the number of criteria, K is the number of alternatives, I is the number of experts, j is the index of criteria (1, …, n), k is the index of alternatives (1, …, K), i is the index of experts (1, …, I) and ${W_{ij}}^{r}$ is the cardinal weight of the j^{th} criterion by the i^{th} expert at the r^{th} rank.

In **fifth** step, a weighted overlay analysis is performed to generate the final suitability map of AVP projects. Using Map Algebra toolset of ArcGIS Pro, each rasterized map is multiplied by the corresponding weight and the results are summed, then multiplied by product of the binary restriction map as expressed in Eq. (3) (Elkadeem et al., 2021).

$$\psi_g = \prod_{i=1}^{n} \mathcal{B}_{i,g} \cdot \sum_{i=1}^{n} W_i \cdot x_{i,g} \tag{3}$$

where ψ_g is the suitability index of the g^{th} grid cell, and $x_{i,g}$ is the standardized score of g^{th} grid cell under criterion i.

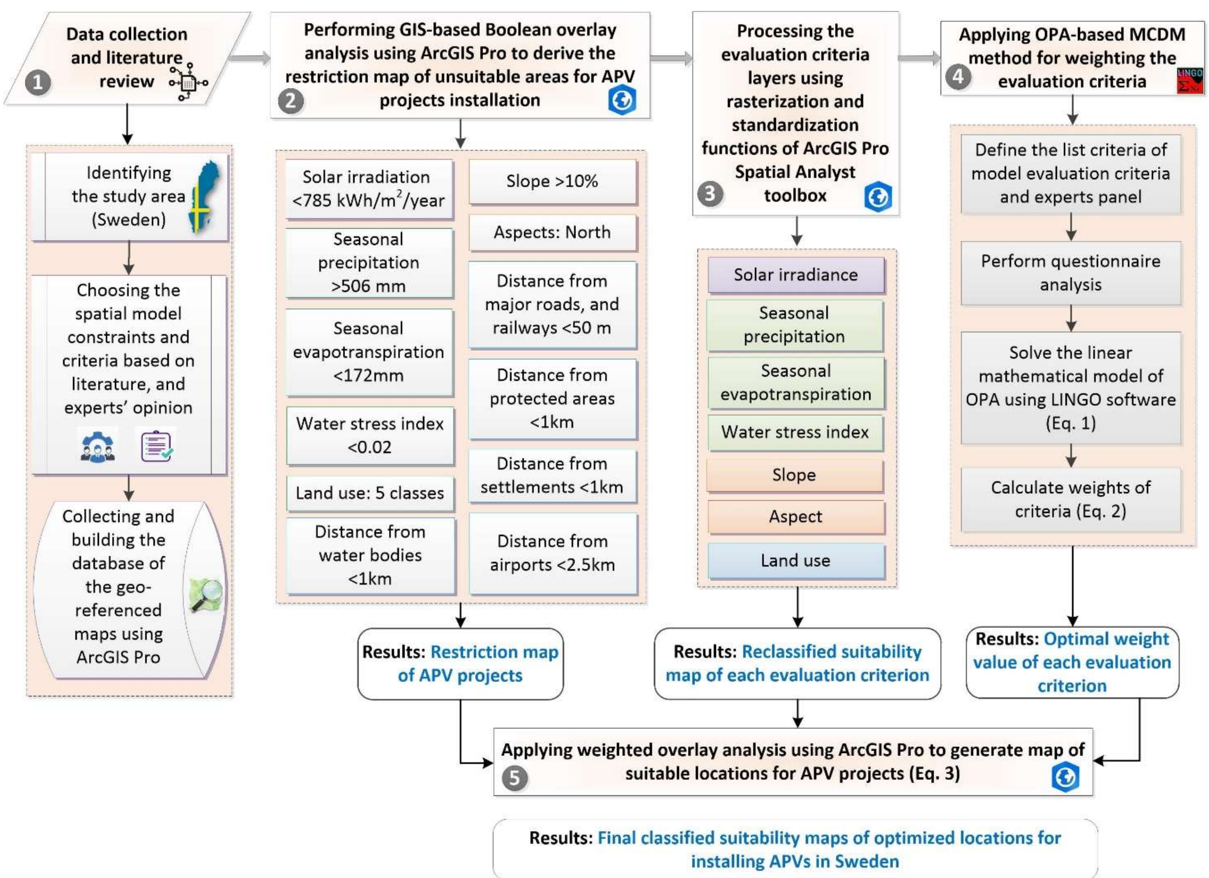


Figure 1: Research method applied for APV sites allocation in Sweden.

Table 1: Buffer values of restriction criteria used in the APV systems geospatial analysis model.

Restriction Criteria	Value	Reference	Comment

Annual global horizontal irradiation (GHI)	<785 $kWh/m^2/year$	Strång (2022)	Data refers to the average for the period 2018-2021 corresponding to the latest version of Strång (2022). The minimum value was approximatively 690 $kWh/m^2/year$ while the maximum value is approximatively 1260 $kWh/m^2/year$. The values were classified in 7 classes of equal interval to define the restriction criteria and to match the suitability classifications of the evaluation criteria.
Seasonal precipitation	>506 mm	SMHI (2022)	The minimum value was 190mm while the maximum value was 570mm. The values were classified in 7 classes of equal interval to define the restriction criteria and to match the suitability classifications of the evaluation criteria.
Seasonal potential evapotranspiration	<172mm	Trabucco, A., & Zomer, R. J. (2018)	The minimum value was 80mm while the maximum value was 637mm. The values were classified in 7 classes of equal interval to define the restriction criteria and to match the suitability classifications of the evaluation criteria.
Water stress index	<0.02	Gassert et al. (2013)	The minimum value was -0.03 while the maximum value was 0.27. The values were classified in 7 classes of equal interval to define the restriction criteria and to match the suitability classifications of the evaluation criteria.
Slope	>10%	Doorga et al. (2019); Settou et al. (2021	
Aspects	North	Saraswat et al. (2021)	
Land use	5 classes	Copernicus (2022)	We have considered as feasible land uses only the following as defined in the reference: • Non-irrigated arable land • Fruit trees and berry plantations • Pastures • Complex cultivation patterns • Land principally occupied by agriculture, with significant areas of natural vegetation
Protected areas	<1km	Watson and Hudson (2015)	Tercan et al. (2021) excluded as unsuitable land the protected areas with a buffer of 0.1 km. In Lindberg et al. (2021). Those areas were considered unsuitable, but no specific buffer was mentioned. The permitting process of one the largest planned solar solar park in Sweden was stopped by Skåne County due to short distance to a protected area, among other things (European Energy, 2022). We used a conservative value of 1 km as reported in

			Watson and Hudson (2015) for heritage and protected areas.
Major roads, and railways	<50m	Halland County (2022).	In Lindberg et al. (2021) the restriction criteria were 10 m for roads and 20 m for railways. According to the Road Act, the protection area is usually twelve meters from the road area but can be up to 50 meters. We have used a conservative 50 m restriction criteria (Halland County, 2022).
Airports	<2.5km	Siyal et al. (2015)	
Water bodies	<0.1km for rivers <0.3km for lakes	Lindberg et al. (2021);	Lindberg et al. (2021) reported that general shore protection within 100 m from water bodies does not allow new constructions or modifications to the landscape (The Swedish Government, 2000). Lindberg et al. (2021) also reported shore protection within 200 m from the major lakes. Västerås municipality reported 300m shore protection from the Mälaren lake (Västerås municipality, 2022).
Settlement	<1km	Tercan et al. (2021); Siyal et al. (2015)	Lindberg et al. (2021) did not consider a specific buffer value for settlement. Settlements mean large communities, only major urbanized areas, not single houses as defined in Copernicus (2022). Lindberg et al. (2021) considered a 100 m buffer for buildings. Nevertheless, as per literature, a buffer for settlement is necessary (e.g., 0.5-2 km) because of the negative visual impact and aesthetics consideration plus the projected future growth of population and urban sprawl.

Table 2: Suitability classifications of the evaluation criteria used in the APV systems geospatial analysis model.

Evaluation criteria	**Suitability class**				
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**
Annual global horizontal irradiation (kWh/m^2/year)	785-880	880-970	970-1060	1,060-1,160	>1160
Seasonal precipitation (mm)	443-506	380-443	316-380	253-316	<253
Seasonal evapotranspiration (mm)	172-265	265-358	358-451	451-544	>544
Water stress index*	0.02-0.07	0.07-0.11	0.11-0.16	0.16-0.21	>0.21
Slope (%)	8-10	6-8	4-6	2-4	0-2
Aspects	NW, NE, N	E, W	SW, SE	S	Flat
Land use	We diversify between pasture as excellent and the rest as poor without middle classes, since this can be supported by the results achieved within the project "Evaluation of the first APV system in Sweden" (Mälardalen University, 2022).				

*Concerning the Water Stress Index, the following reference classification is from Gassert et al. (2013): 0-0.1 (Low), 0.1-0.2 (Low-Medium), 0.2-0.4 (Medium), 0.4-0.8 (High), >0.8 (Extremely High)

3 Results and discussion

The results of the OPA-MCDM algorithm for optimal weights of evaluation criteria are provided in Table 3, together with the list of the experts who participated in the questionnaire analysis and their preference rank for the evaluation criteria based on their experiences and knowledge. The results highlight that global solar irradiation is found to be the most influential criterion on the APV project planning, with the highest weight value of 30.15 %, followed by aspects (17.3%) and land use (C7) (16.36%). On the other hand, the slope and seasonal precipitation criteria are deduced to have the lowest weight values of 5.7% and 8.8%, respectively.

Table 3: OPA-MCDM weighting results.

Expert name	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	**Optimal weights by OPA model**
Expert rank	7	6	8	2	1	5	4	10	12	9	11	3	
Criterion name	**Preference rank of criteria by experts**												
C1	1	1	5	1	1	2	1	2	4	1	4	2	0.30155
C2	6	6	4	7	4	5	5	5	5	3	5	3	0.08839
C3	7	7	3	5	3	6	4	4	2	5	6	7	0.10514
C4	5	5	2	4	5	7	6	3	1	4	7	4	0.11125
C5	2	4	6	3	2	1	2	6	7	2	3	5	0.17300
C6	4	3	7	6	7	3	7	7	6	6	1	6	0.05706
C7	3	2	1	2	6	4	3	1	3	7	2	1	0.16361

Notes: E1: Researcher 1, E2: Researcher 2, E3: Researcher 3, E4: Researcher 4, E5: Researcher 5, E6: Farmer 1, E7: Farmer 2, E8: PV park developer 1, E9: PV park developer 2, E10: Agronomist 1, E11: Agronomist 2, E12: Independent power producer. C1: Global solar irradiation, C2: Seasonal precipitation, C3: Seasonal evapotranspiration, C4: Water stress index, C5: Aspects, C6: Slope, C7: Land use.

According to Table 2, the geospatial maps showing the suitability classifications of each criterion are processed through ArcGIS Pro processing tools and presented in Figure 2. The restriction map obtained based on the buffer zones defined in Table 1 is overlaid with the evaluation criteria maps under the optimal weights calculated by OPA. Using the Weighted Overlay tool in ArcGIS, the final suitability map is derived and depicted in Figure 3. The results concerning the land area corresponding to each suitability class for the whole country are given in Table 4. 8.55% of the Swedish territory, approximately 38,485 km^2, is suitable for installing APV systems. Among this area, less than 1% is classified as "excellent", about 15% as "very good", about 72% as "good", about 13.1% as "moderate", and less than 0.1% as "poor". The results per county are summarized in Table 5. As expected, the results of the suitability analysis are highly dependent on the list of assumptions, criteria, and values defined in Table 1 and Table 2. For instance, the higher percentage of suitable areas belonging to "excellent", and "very good" classes are in the southern part of Sweden, which are marked out by high solar irradiation. Most "excellent"-classified areas are in Kalmar, Skåne, and Gotland, in the South of Sweden. In contrast, most "very good" sites are in Skåne, Kalmar and Östergötland. The potential areas for installing APV systems in Sweden diversified per county, land use class, and suitability class can be found in the Appendix (Table A1).

Assuming a configuration as in the first APV system in Sweden (i.e., vertically mounted east-west oriented APV system with bifacial PV modules and 10 m rows spacing) (Campana et al., 2021), 1 ha of land corresponds to approximately 388 kW_p. This power-to-land area ratio agrees with the range between 0.2 and 0.9 MW/ha for different APV system designs reported in Chatzipanagi et al. (2023). The potential electricity production from the APV systems in Sweden is shown in Figure 4, where a comparison is provided with the electricity consumption in 2021 (equal to 143.04 TWh [Statistics Sweden, 2023]) and forecasted electricity production in 2050 differentiated for four different electrification scenarios (Svenska kraftnät, 2021). The specific output per county (i.e., $kWh/kW_p/1^{st}$ year) calculated with PVsyst® for each capital city of the investigated counties are provided in the Appendix. We have assumed that the specific electricity production per county is equal to the specific production of the county's capital city without considering spatially distributed calculations of the electricity production. As seen in Figure 4, the total "excellent" areas can potentially supply 2.44 TWh against the electricity consumption in 2021 of 143.04 TWh. On the other hand, the land classified as "excellent" and "very good" could potentially provide about 206.6 TWh, which is a much higher production capacity than the 2021 electricity consumption and still higher than two of the forecasted electricity consumptions in 2050 for two specific electrification scenarios. The total land area of the land classified as "excellent" and "very good" account for 14.8% of the entire Swedish territory classified as suitable. The land classified as "excellent", "very good", and "good" could potentially provide about 1,192.1 TWh, which is a much higher production capacity than the 2050 forecasted electricity consumption in the most aggressive electrification scenario of 298 TWh (Svenska kraftnät (2021). The County of Skåne shows the greatest potentials in terms of land classified as "very good" with about 92.8 TWh, and a total potential for APV systems of about 205.8 TWh. Västra Götaland shows the highest potentials in terms of electricity production for a total of about 226.5 TWh but mostly (i.e., about 84%) from areas classified as "good".

The potential of APV electricity production per land use is depicted in Figure 5. Pastureland can supply 80.3 TWh/year, about 56% of the total electricity consumption in 2021. The experimental results from the first APV system in Sweden, installed on pastureland, showed for 2021 and 2022 no significant difference between ley grass samples yield under the APV system and ley grass samples yield in open-field conditions. Thus, considering that the supporting structure for vertically mounted APV systems reduces the effective crop area by about 5-10%, land classified as pastureland in Sweden could supply 51% of the total electricity consumption in 2021 while maintaining 90-95% of the potential pastureland grass yield.

The potential installed capacity of APV systems is depicted in Figure 6 as a function of land suitability class, land use, and County. The total potential installed capacity for "excellent" areas is 2.3 GW_p, while for areas classified "excellent" and "very good" is 201 GW_p. The potentials of "pastures" is 87 GW_p. To contextualize our results, in the study conducted by Chatzipanagi et al. (2023), based also on the results from Kougias et al. (2021), to reach the PV goal of the Swedish National Energy and Climate Plan for 2030 (new policy trends) of 3.5 GW_p, 0.2% of the utilised agricultural area would be required through the installation of APV systems. The estimation assumes an average power-to-land area ratio of 0.6 MW_p/ha. In our study, assuming a power-to-land area ratio of approximatively 0.39 MW_p/ha, the 3.5 GW_p goal can be attained using the 0.23% of the total suitable areas for installing APV systems (i.e., 38,485 km^2). The mismatch in area percentages between our study and the study conducted by Chatzipanagi et al. (2023) is connected to the assumed power-to-land area ratio and the total agricultural areas. Chatzipanagi et al. (2023) used Eurostat statistics from 2013 on the utilised agricultural areas (UAA), which include arable land, permanent grassland, permanent crops, and market (kitchen) gardens (Eurostat, 2023b), and amount to approximately 30,359 km^2. In our study, the agricultural areas data is from the most recent Corine Land Cover (CLC2018) product (Copernicus, 2023a), which includes non-irrigated arable land (75.37%), land principally occupied by agriculture with significant areas of natural vegetation (14.74%), pastures (6.66%), complex cultivation patterns (3.18%), and fruit trees and berry plantations (0.05%), and amount to approximatively 39,734 km^2. CLC2018 can provide updated and spatially-explicit information on the agricultural land distribution in Sweden at a spatial resolution of 100m and with an overall accuracy of about 95% for both blind and plausibility analysis (Copernicus, 2023b&2023c) and serve as a good reference input layer for this work. The main difference between statistical data and CLC2018 is that statistics show utilised agricultural areas, while CLC2018 reports areas that are physically used or could be used as agricultural areas. Thus, we have decided to use CLC2018 because it provides the potential of APV systems, intended as a technology for providing services to currently used agriculture areas and increasing agricultural areas.

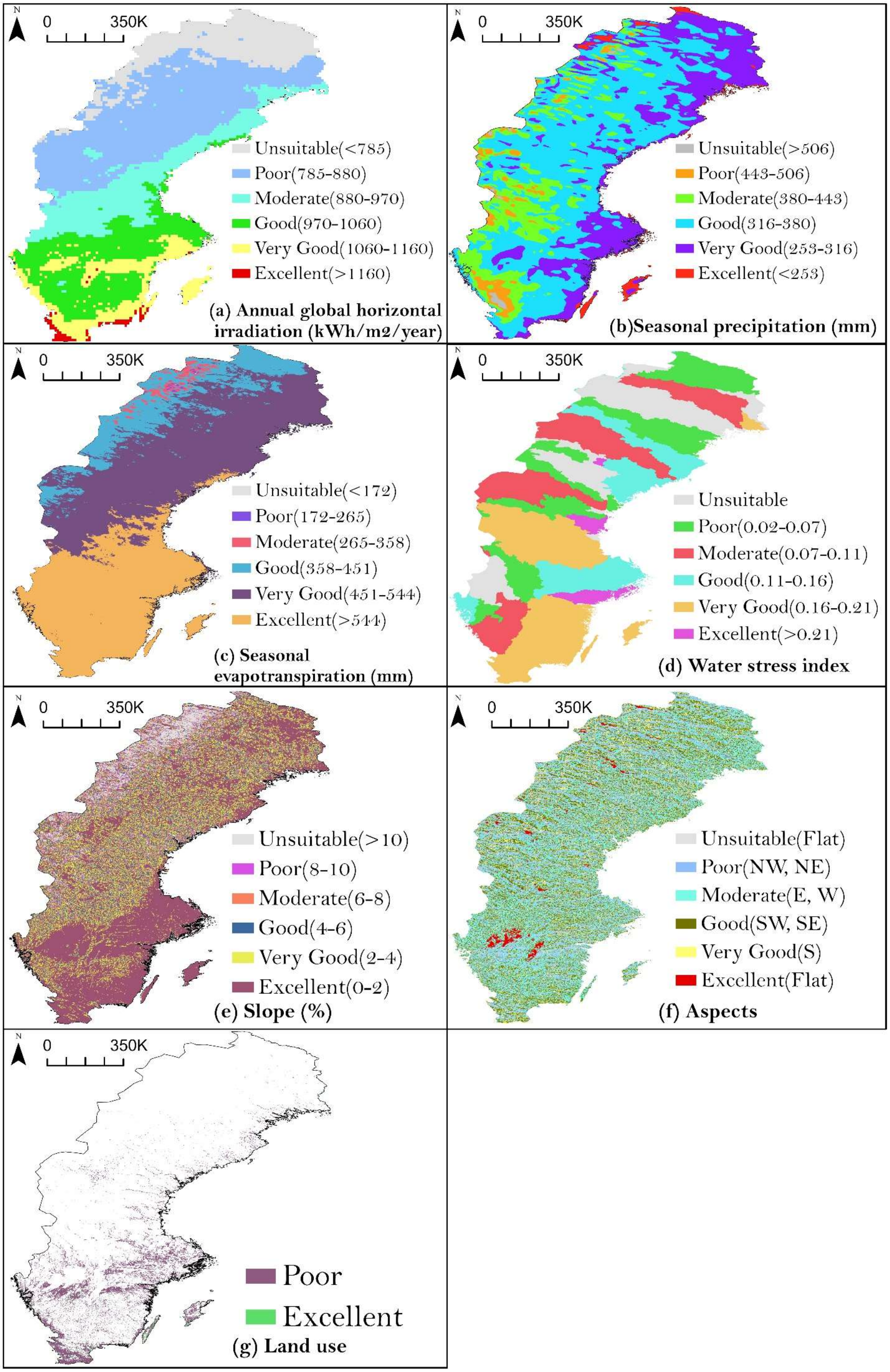


Figure 2: Geospatial suitability maps of evaluation criteria.

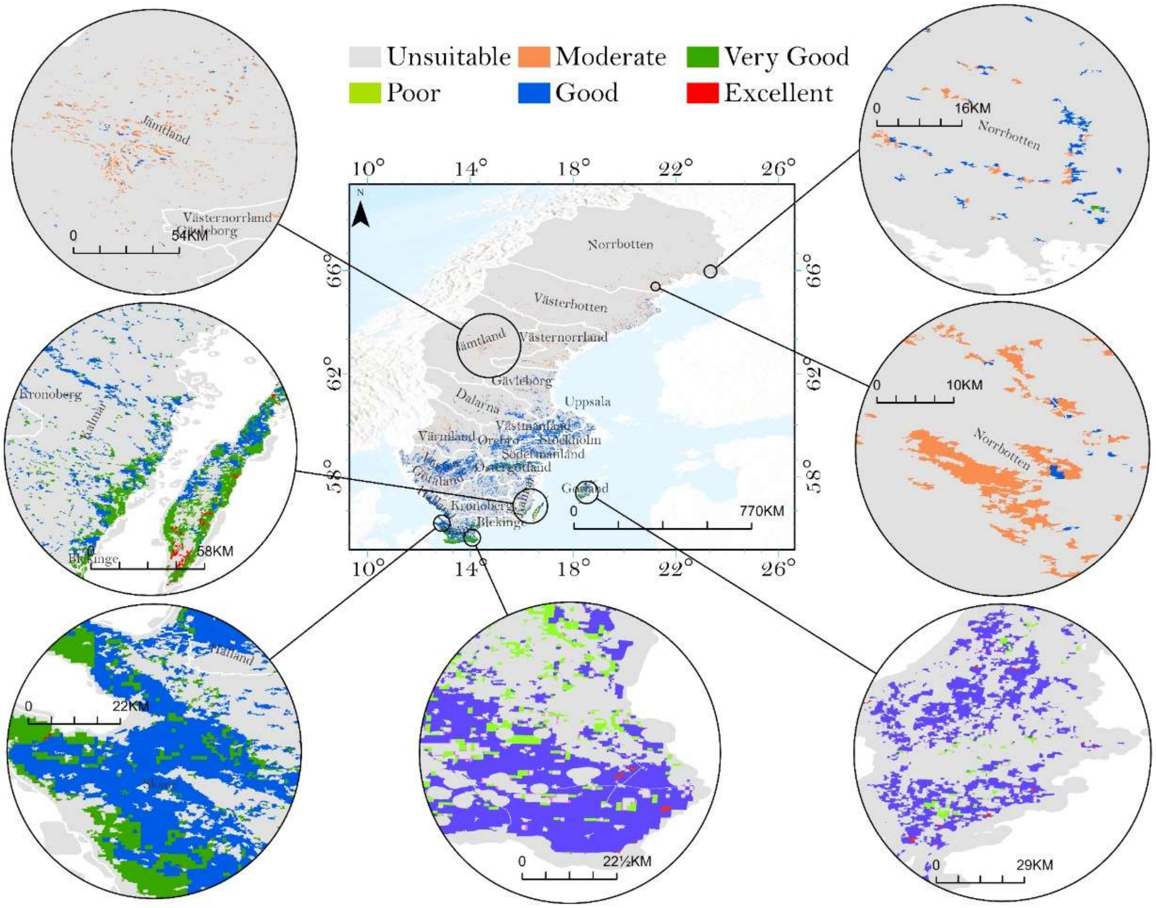


Figure 3: Final suitability map of APV projects over the Swedish territory.

Table 4. Geospatial analysis results of the planimetric areas and their percentages in Sweden.

Item	Area (km^2)	%	Suitability class		
Suitable area	38,485.04	8.55	**Class**	**Area (km^2)**	**%**
			Poor	31.54	0.08
			Moderate	5,039.61	13.09
			Good	27,709.32	72.00
			Very Good	5,639.25	14.65
			Excellent	65.32	0.17
Restricted area	411,562.23	91.45	-		
Total land area	450,047.27	100.00	-		

Table 5. Geospatial analysis results of the planimetric areas and their percentages for the twenty-one counties in Sweden.

County name	Total county's area	Land suitability class					Total suitable area	Total unsuitable area
		Poor	Moderate	Good	Very Good	Excellent		
Västra Götaland	29,691.29	0	931.84	5,655.92	122.34	0	6,710.10	2,2981.19
Västmanland	6,921.07	0	16.86	1,612.46	22.74	0	1,652.06	5,269.01
Västernorrland	22,962.93	10.36	700.5	219.41	0.47	0	930.74	2,2032.19
Västerbotten	59,193.91	5.86	735.96	386.13	1.6	0	1,129.55	5,8064.36
Värmland	21,958.14	0	715.07	922.15	5.71	0	1,642.93	2,0315.21
Uppsala	7,454.91	0	0	1,985.26	96.93	0	2,082.19	5,372.72
Stockholm	7,195.05	0	0	1,082.2	159.59	0.32	1,242.11	5,952.94
Södermanland	7,040.26	0	4.04	1,774.91	140.94	0	1,919.89	5,120.37
Skåne	11,285.76	0	2.76	3,187.17	2,627.32	10.35	5,827.60	5,458.16
Östergötland	12,289.70	0	0.03	2,311.09	666.12	0	2,977.24	9,312.46
Orebro	9,680.57	0	59.73	1,391.17	30.89	0	1,481.79	8,198.78
Norrbotten	106,115.89	8.01	476.87	162.3	3.08	0	650.26	105,465.63
Kronoberg	9,432.97	0	4.86	827.63	61.09	0	893.58	8,539.39
Kalmar	11,627.76	0	0.78	1,140.97	755.3	39.58	1,936.63	9,691.13
Jönköping	11,077.42	0	20.47	1,346.72	94.29	0	1,461.48	9,615.94
Jämtland	54,187.91	7.31	699.51	90.74	0	0	797.56	53,390.35
Halland	5,712.08	0	120.52	1,392.69	35.93	0	1,549.14	4,162.94
Gotland	3,182.21	0	0	610.92	545.03	9.41	1,165.36	2,016.85
Gävleborg	19,658.83	0	316.09	688.68	8.75	0	1,013.52	18,645.31
Dalarna	30,395.01	0	233.72	766.26	7.29	0	1,007.27	29,387.74
Blekinge	2,983.60	0	0	154.54	253.84	5.66	414.04	2,569.56

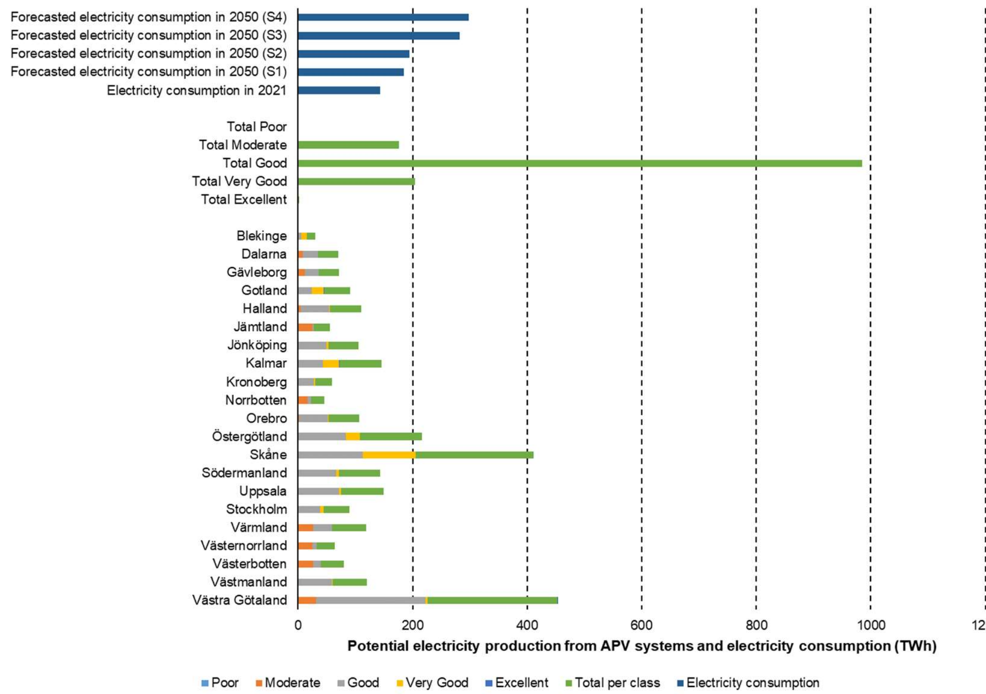


Figure 4: Potential electricity production from APV systems in Sweden differentiated for land suitability class and County. The potential electricity production has been compared with the 2021 electricity production and the forecasted electricity consumption in 2050 based on different electrification scenarios (Statistics Sweden, 2023; Svenska kraftnät, 2021).

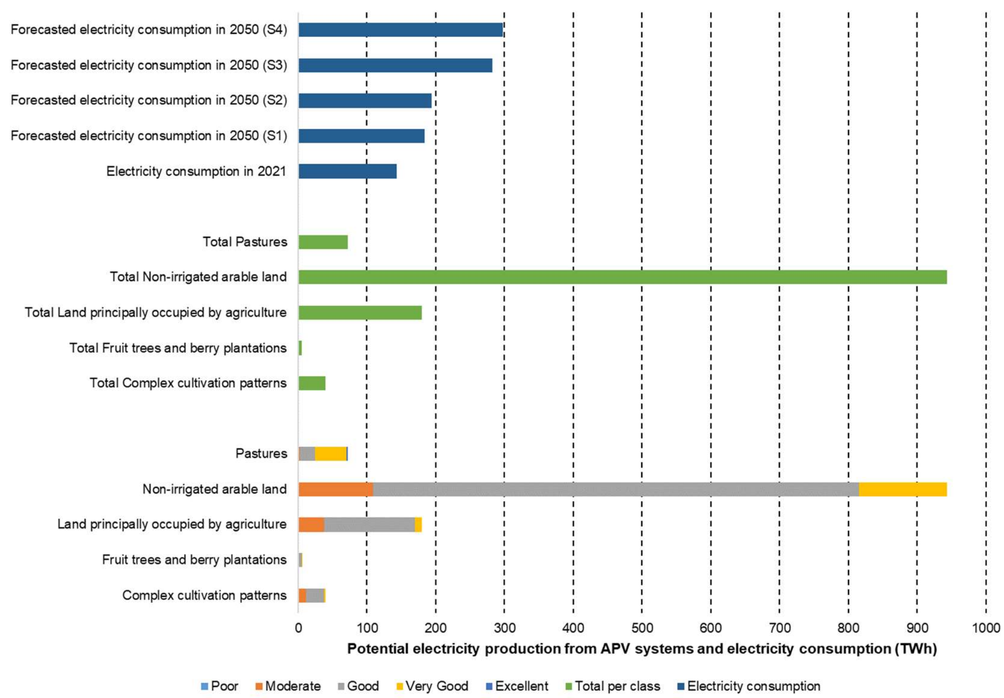


Figure 5: Potential electricity production from APV systems in Sweden differentiated for land suitability class and land use. The potential electricity production has been compared with the 2021 electricity production and the forecasted electricity consumption in 2050 based on different electrification scenarios (Statistics Sweden, 2023; Svenska kraftnät, 2021).

According to Swedish law, agricultural land that is suitable for cultivation is of "national importance" and it cannot be exploited for other purposes unless it is to satisfy a significant national interest and there is no other possible land to use (Chapter 3, Section 4) (The Swedish Government, 2000). In this study, as pointed out in the introduction, APV systems are defined as a technology to support agriculture and agricultural activities. Although implementing APV systems might reduce crop production at high latitudes (Campana et al., 2021), implementing APV systems can significantly boost farmers´ economies, especially for smallholder farmers. Increasing farmers´ economies is a pivotal concept that policymakers and stakeholders should further investigate since adopting APV systems can lead to a decreased farm-level crop production and area (i.e., in the order of 5-10% with vertically mounted APV systems) but can simultaneously lead to a reverse trend of the regional and national agricultural area, number of farms, and thus domestic crop production. As shown in Figure 7, the agricultural land area, and the number of farms in Sweden have continuously decreased since the 1970s (FAO, 2023; Jordbruksverket, 2023). Improving farming economies can reverse this trend. Thus, the adoption of APV systems, as defined in this study, does not conflict with the Swedish Environmental Code since agriculture and electricity are both national priorities, and APV systems can potentially increase food production on a regional or national scale while supporting clean energy conversion.

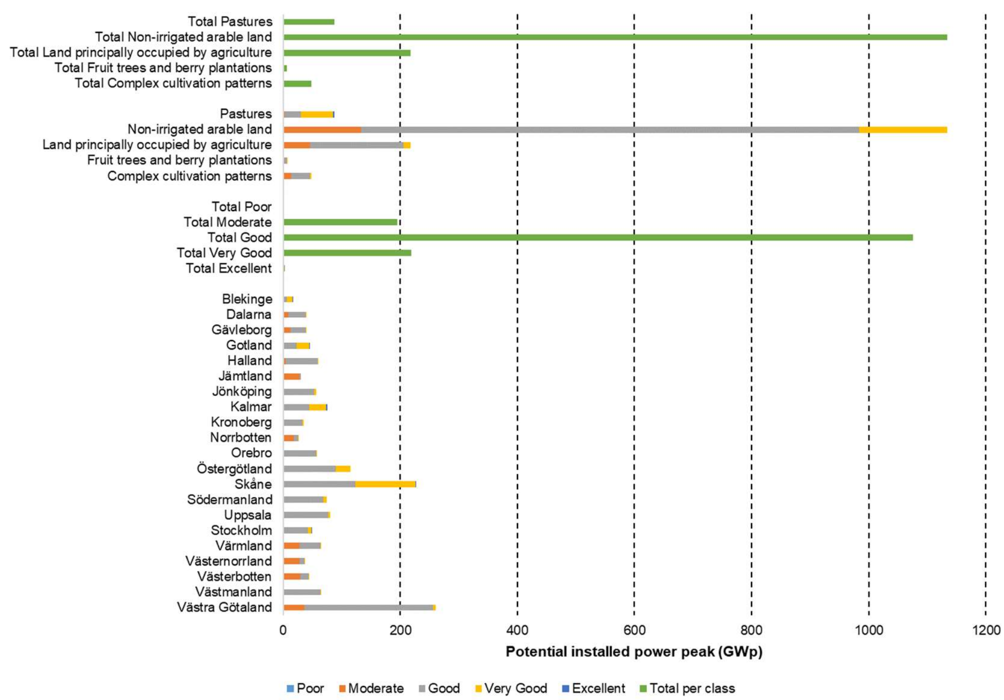


Figure 6: Potential installed capacity for APV systems in Sweden differentiated for land suitability class, land use, and County. The potential installed capacity has been calculated assuming vertically mounted APV systems with bifacial PV modules and 10 m rows spacing yielding to approximately 388 kW_p/ha.

Although we selected agricultural land as a feasible area for APV systems in this study, this paper does not aim to promote the uncontrolled installation of conventional PV systems on productive and fertile land for food production. This study aimed to find suitable and optimal locations for APV systems defined by the European Commission Joint Research Centre (Chatzipanagi et al., 2022; Chatzipanagi et al., 2023) as systems with the primary function of supporting agriculture while converting solar energy into electrical energy. This study was not aimed at finding suitable and optimal areas for APV systems intended as underhanded integration of agricultural activities with PV systems only to attain easier and faster permitting processes. This threat calls for two critical suggestions. First, as performed in other countries like France, Germany, Italy, and Japan, the Swedish Government should clearly define APV systems and furthermore categorise them based on performance. This decision-making process should involve all the stakeholders affected by the installation and operation of APV systems, for instance, representatives of farmers, PV park developers, and water management agencies, to cite some. Second, as performed or being performed in other countries, guidelines should be developed to manage the integration of PV systems and agricultural activities, define standards, pose limits to the agricultural yield reduction under APV conditions, and identify the most suitable or optimal areas for implementing APV systems, to cite some.

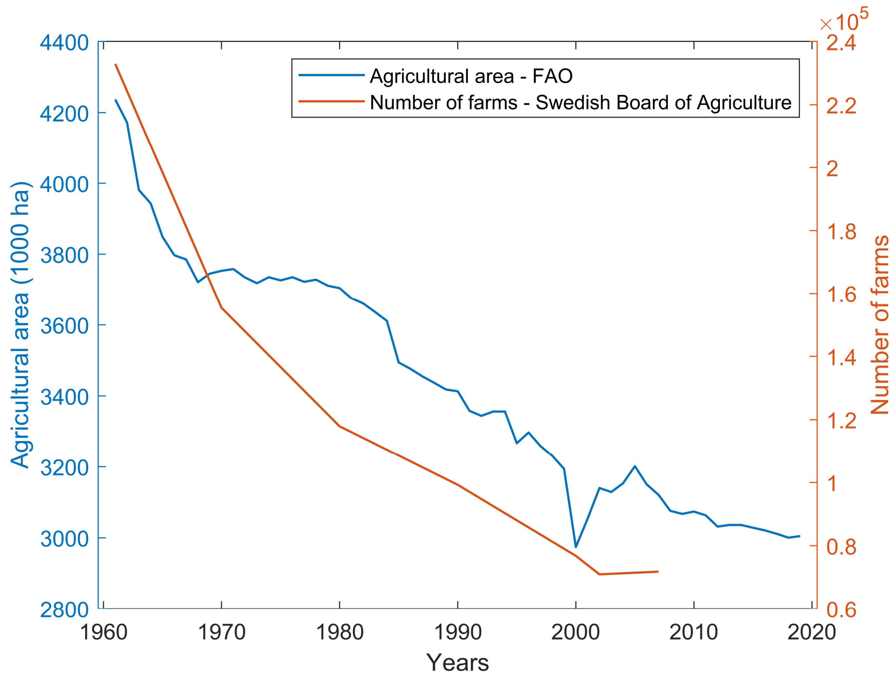


Figure 7: Statistics concerning agricultural land and number of farms in Sweden (FAO, 2023; Jordbruksverket, 2023).

In countries such as France, Germany, Italy, and Japan, one of the main issues around APV systems is not to use or not agricultural land but mainly to define APV systems, to maintain and monitor the agricultural production under the APV systems, and to set a limit on the agricultural yield production under shading conditions as compared to open-field conditions. In France, the law does not yet set any constraints on the agricultural production below APV systems or concerning the maximum threshold for the coverage area of PV modules but defines APV systems as systems where the colocation of agricultural activities and solar PV energy conversion is possible but agricultural production should be maintained and developed (Chatzipanagi et al., 2023; Légisfrance, 2023). Further, an APV system should provide at least one of the following services a) Improvement of the agronomic potential and impact, b) Adaptation to climate change, c) Protection against hazards, d) Improvement of animal welfare. In Germany, the Fraunhofer ISE, the University of Hohenheim, the German Institute for Standardization (DIN), and representatives from academia and industry have developed the standard DIN SPEC 91434 "Agri-photovoltaic systems — Requirements for primary agricultural use". The guidelines, among other specifications, set a threshold for the agricultural yield under APV systems to be at least 66% of the reference yield and categorise APV systems in different

categories for which the land loss cannot be more than 10%, for category I, or 15 % for category II. In Italy, the guidelines for APV systems state that at least 70% of the agricultural areas should be kept for agricultural activities (Italian Ministry of the Environment and Energy Security, 2023). The ratio between the total surface area of the APV system and the total area occupied by the APV system should be lower than 40%. In Japan, the law has institutionalised and promoted APV systems since 2013 through directives from the Ministry of Agriculture, Forestry and Fisheries, and feed-in tariff Law (US Department of Energy, 2022; Kimura, 2017). The Japanese law supported APV systems as a key integrated technology to support the Japanese agricultural sector and fight the abandonment process of farmland. The legislation allows the operation of APV farms only if the crop yield under an APV system is at least 80% compared to the yield before APV installation (US Department of Energy, 2022; Gonocruz et al., 2022). The potential of APV farms in Japan was estimated as 280 GW_p is all the abandoned farmlands could be converted (Tajima and Iida, 2021).
One of the key actions highlighted by Chatzipanagi et al. (2023) for the large-scale deployment of APV systems is identifying and classifying the potential agricultural lands for APV systems using GIS techniques. This study, in line with the recent Joint Research Centre report and with the suggested actions for the Swedish Government, has contributed to identifying suitable areas for the APV system in Sweden by further classifying them. In this study, the suitable areas for APV systems have been identified and classified based on one of the primary services that APV systems could provide to agriculture: reduced evapotranspiration and temperature stresses and, thus, climate adaptation.

4 Conclusions

In this study, we have developed a procedure to identify and classify suitable areas for APV systems in Sweden. A five-step GIS-MCDM approach. In the first step, different techno-agro-socio-economic criteria of interest to find the optimal locations of APV systems projects in Sweden are identified. In the second step, the constrained map reflecting the unsuitable areas for APV systems implementation is derived by via Boolean overlay analysis. In the third step, the suitability map for each evaluation criterion is produced. In the fourth step, an OPA algorithm is established to calculate the weights of the selected evaluation criteria through expert interviews. In the last step, a weighted overlay analysis is performed to generate the final suitability map of AVP projects. The main conclusion that can be drawn from this study are the following:

1. Approximately 8.55% of the Swedish territory, approximatively 38,485 km^2, is suitable for the installation of APV systems. Among this area, 0.17% is classified as “excellent”, approximately 15% as “very good”, about 72% as “good”, about 13.1% as "moderate", and less than 0.1% as “poor”.
2. The total “excellent” areas can potentially supply 2.44 TWh against the electricity consumption in 2021 of about 143 TWh.
3. The land classified as “excellent” and “very good” could potentially provide about 2,206.6 TWh that is a much higher production capacity than the 2021 electricity consumption and still higher than two of the forecasted electricity consumption in 2050 for two specific electrification scenarios. The total land area classified as “excellent” and “very good” account for 14.8% of the total Swedish territory classified as suitable for installing APV systems.
4. Pastureland can supply 84.80 TWh/year that is about 60% of the total electricity consumption in 2020.
5. The total potential installed capacity for "excellent" areas is 2.3 GW_p, while for areas

classified "excellent" and "very good" is 201 GW_p. The potentials of "pastures" is 87 GW_p.

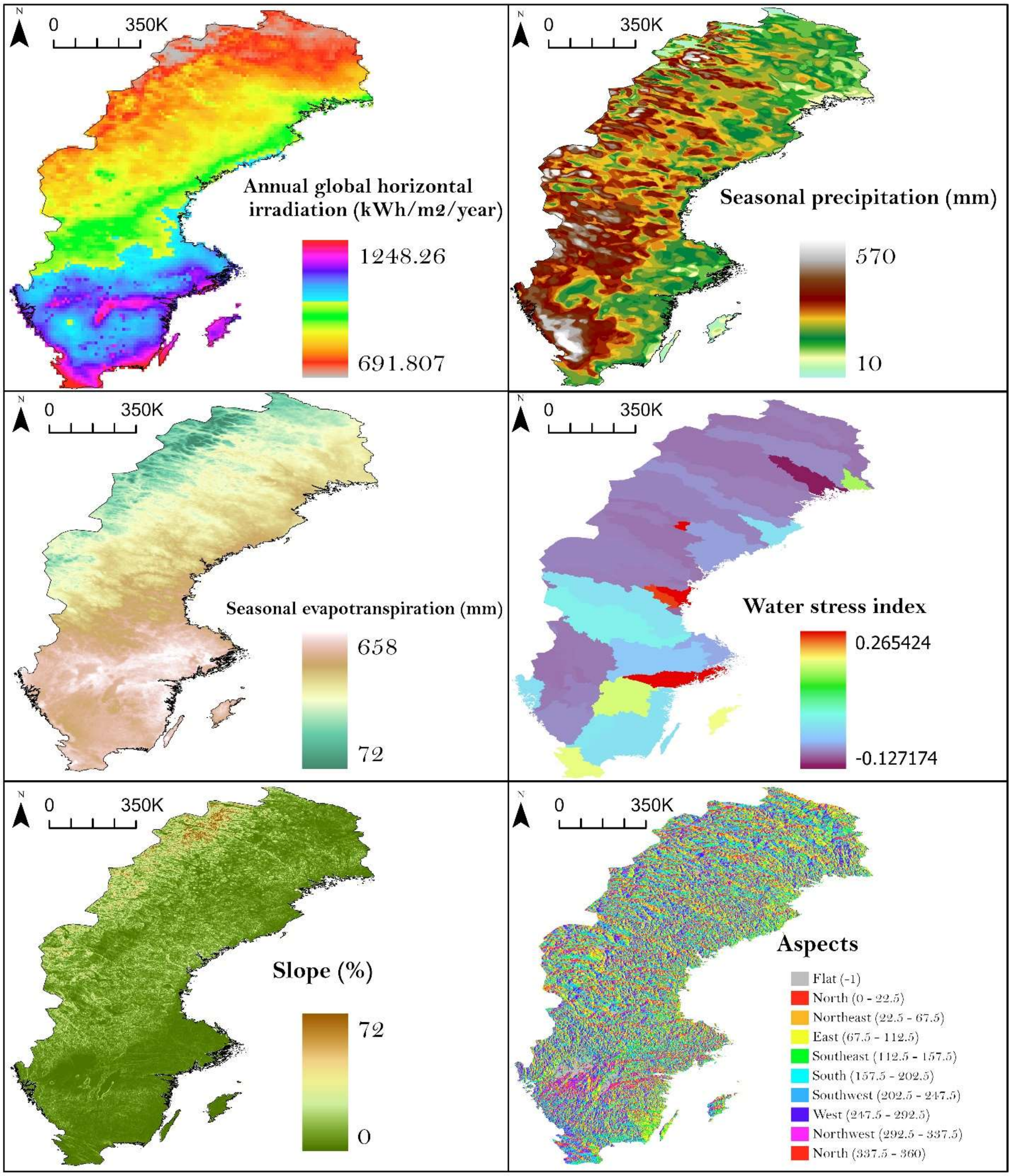
Although in this study we selected agricultural land as a feasible area for APV systems, the aim of this paper is not to promote the uncontrolled installation of conventional PV systems on productive fertile land for food production. This study aimed at finding suitable and optimal locations for APV systems defined as systems with the primary function of supporting agriculture.
The approach developed in this study has been applied to Sweden but has a general validity and can be expanded to a larger geographical area and improved by adding further techno-agro-socio-economic criteria and using higher resolution data. Future studies may also investigate the variation of the criteria weights and values defined for buffer and suitability grades through sensitivity analysis for a more generalized approach and better interpretation of the results.

Acknowledgements

The authors thank the Swedish Knowledge Foundation for the funding received through the project Optimized design of agrivoltaic systems in Sweden (Opti-APV) (20220032-H-01) co-founded by Linde Energi AB and Solkompaniet Sverige AB. The last and corresponding author acknowledges Formas - a Swedish Research Council for Sustainable Development, for the funding received through the early career project "*Avoiding conflicts between the sustainable development goals through agro-photovoltaic systems*", grant number FR-2021/0005. The authors also acknowledge the financial support received from the Swedish Energy Agency through the project "*Evaluation of the first agrivoltaic system in Sweden*", grant number 51000-1. The authors also acknowledge the funding received from the Swedish Energy Agency through the project "*SOLVE*", grant number 52693-1. The views, opinions, findings, and conclusions or recommendations expressed in this study are strictly those of the authors. They do not necessarily reflect the views of the funding agencies and co-funding partners.

Appendix

The raw input maps used to identify the suitable areas for the installation of APV systems in Sweden are depicted in Figure A.1. Table A1 summarizes the detailed of the suitable areas for APV systems diversified per county, land use class, and suitability class. The specific electricity production (kWh/kW_p/ 1st year) for the capital cities of the investigated counties are provided in Table A2. The electricity production has been calculated with PVSyst® assuming 400 W_p bifacial modules Jinkosolar model JKM400M-72H-TV coupled with four inverters SMA Sunny Highpower SHP100-20-PEAK3. These components' set-up, assuming an available area for modules of 2000 m^2, lead to an APV system capacity of 388 kW_p.



0
350K
Annual global horizontal irradiation (kWh/m2/year)
1248.26
691.807
Seasonal precipitation (mm)
570
10
Seasonal evapotranspiration (mm)
658
72
Water stress index
0.265424
-0.127174
Slope (%)
72
0
Aspects
Flat (-1)
North (0 - 22.5)
Northeast (22.5 - 67.5)
East (67.5 - 112.5)
Southeast (112.5 - 157.5)
South (157.5 - 202.5)
Southwest (202.5 - 247.5)
West (247.5 - 292.5)
Northwest (292.5 - 337.5)
North (337.5 - 360)

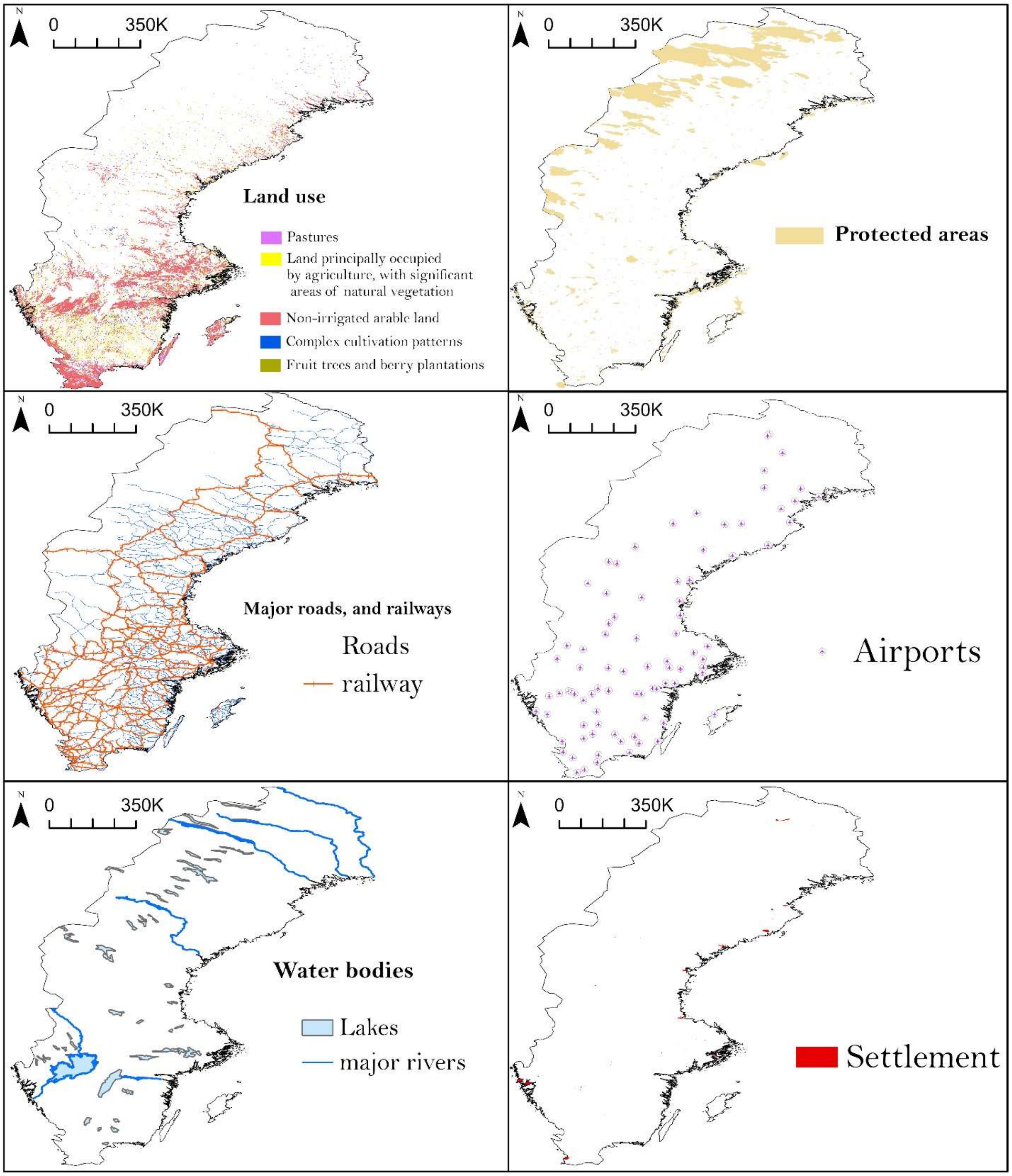


Fig. A1: Raw maps of the twelve criteria applied for evaluation of APV projects in Sweden.

Table A1: Details of the suitable areas for APV systems diversified per county, land use class, and suitability class.

Västra Götaland						
Land use type	**Poor**	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	207.2	100.79	0	307.99
Land principally occupied by	0	219.96	799.74	2.97	0	1,022.67
Non-irrigated arable land	0	656.62	4,402.9	15.26	0	5,074.78
Complex cultivation patterns	0	27.63	122.71	1.66	0	152
Fruit trees and berry plantations	0	27.63	123.37	1.66	0	152.66
Total	0	931.84	5,655.92	122.34	0	6710.1

Västmanland						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	9.8	21.85	0	31.65
Land principally occupied by	0	2.2	96.4	0.12	0	98.72
Non-irrigated arable land	0	13.62	1,471.43	0.77	0	1,485.82
Complex cultivation patterns	0	1.04	34.83	0	0	35.87
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	16.86	1,612.46	22.74	0	1,652.06

Västerbotten						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	8.92	34.3	1.6	0	44.82
Land principally occupied by	4.18	251.99	61.38	0	0	317.55
Non-irrigated arable land	0.36	438.96	283.87	0	0	723.19
Complex cultivation patterns	1.32	36.09	6.58	0	0	43.99
Fruit trees and berry plantations	0	0	0	0	0	0
Total	5.86	735.96	386.13	1.6	0	1,129.55

Västernorrland						
	Poor	Moderate	Good	Very Good	Excellent	**Total**
Pastures	0	6.48	18.65	0.47	0	25.6
Land principally occupied by	4.54	212.6	46.62	0	0	263.76
Non-irrigated arable land	5.16	443.55	147.96	0	0	596.67
Complex cultivation patterns	0.65	37.44	6.18	0	0	44.27
Fruit trees and berry plantations	0	0.43	0	0	0	0.43
Total	10.35	700.5	219.41	0.47	0	930.73

Värmland						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0.24	30.9	5.65	0	36.79
Land principally occupied by	0	143.99	82.21	0	0	226.2
Non-irrigated arable land	0	504.24	775.32	0.06	0	1,279.62
Complex cultivation patterns	0	66.14	33.57	0	0	99.71
Fruit trees and berry plantations	0	0.45	0.02	0	0	0.47
Total	0	715.06	922.02	5.71	0	1,642.79

Stockholm						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	6.47	53.77	0.32	60.56
Land principally occupied by	0	0	185.82	13.09	0	198.91
Non-irrigated arable land	0	0	854.1	89.19	0	943.29
Complex cultivation patterns	0	0	35.81	3.54	0	39.35
Fruit trees and berry plantations	0.36	0	0	0	0	0.36
Total	0.36	0	1,082.2	159.59	0.32	1,242.47

Uppsala						
Pastures	0	0	25.77	45.37	0	71.14
Land principally occupied by	0	0	147.26	1.39	0	148.65
Non-irrigated arable land	0	0	1,763.75	49.88	0	1,813.63
Complex cultivation patterns	0	0	48.48	0.29	0	48.77
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	0	1,985.26	96.93	0	,2082.19

Södermanland						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	21.32	32.67	0	53.99
Land principally occupied by	0	0.18	172.9	7.8	0	180.88
Non-irrigated arable land	0	3.45	1,520.69	97.23	0	1,621.37
Complex cultivation patterns	0	0.41	60	3.24	0	63.65
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	4.04	1,774.91	140.94	0	1,919.89
Skåne						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures			13.76	449.54	10.35	473.65
Land principally occupied by	0	0	184.01	47.99	0	232
Non-irrigated arable land	0	2.76	2,959.02	2,113.2	0	5,074.98
Complex cultivation patterns	0	0	24.03	12.62	0	36.65
Fruit trees and berry plantations	0	0	6.35	3.97	0	10.32
Total	0	2.76	3,187.17	2,627.32	10.35	5,827.6
Östergötland						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	18.42	152.87	0	171.29
Land principally occupied by	0	0	277.55	44.1	0	321.65
Non-irrigated arable land	0	0.03	1,903.09	457.22	0	2,360.34
Complex cultivation patterns	0	0	111.65	11.93	0	123.58
Fruit trees and berry plantations	0	0	0.38	0	0	0.38
Total	0	0.03	2,311.09	666.12	0	2,977.24
Orebro						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	16.2	22.35	0	38.55
Land principally occupied by	0	15.35	95.23	0	0	110.58
Non-irrigated arable land	0	40.63	1,238.07	8.54	0	1,287.24
Complex cultivation patterns	0	3.75	41.67	0	0	45.42
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	59.73	1,391.17	30.89	0	1,481.79
Norrbotten						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	48.56	119.32	3.08	0	170.96
Land principally occupied by	2.65	51.87	1.7	0	0	56.22
Non-irrigated arable land	3.46	360.54	40.05	0	0	404.05
Complex cultivation patterns	1.9	15.83	1.21	0	0	18.94
Fruit trees and berry plantations	0	0	0	0	0	0
Total	8.01	476.8	162.28	3.08	0	650.17
Kronoberg						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	18.72	49.63	0	68.35
Land principally occupied by	0	4.02	450.96	7.55	0	462.53
Non-irrigated arable land	0	0.63	325.17	3.65	0	329.45
Complex cultivation patterns	0	0.21	32.78	0.26	0	33.25
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	4.86	827.63	61.09	0	893.58
Kalmar						

	Poor	Moderate	Good	Very Good	Excellent	Total
Pastures	0		10.03	227.39	39.58	277
Land principally occupied by	0	0.33	412.87	106.79	0	519.99
Non-irrigated arable land	0	0.45	677.35	415.35	0	1,093.15
Complex cultivation patterns	0	0	39.36	5.6	0	44.96
Fruit trees and berry plantations	0	0	1.36	0.17	0	1.53
Total	0	0.78	1,140.97	755.3	39.58	1,936.63
			Jönköping			
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	42.32	72.66	0	114.98
Land principally occupied by	0	13.24	645.2	2.84	0	661.28
Non-irrigated arable land	0	4.91	535.32	17.29	0	557.52
Complex cultivation patterns	0	2.32	123.56	1.5	0	127.38
Fruit trees and berry plantations	0	0	0.32	0	0	0.32
Total	0	20.47	1,346.72	94.29	0	1,461.48
			Jämtland			
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**sum**
Pastures	0	15.55	51.24	0	0	66.79
Land principally occupied by	4.3	158.84	4.26	0	0	167.4
Non-irrigated arable land	1.11	433.53	33.76	0	0	468.4
Complex cultivation patterns	1.9	91.59	1.48	0	0	94.97
Fruit trees and berry plantations	0	0	0	0	0	0
Total	7.31	699.51	90.74	0	0	797.56
			Halland			
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	22.21	26.6	0	48.81
Land principally occupied by	0	48.06	206.48	0.86	0	255.4
Non-irrigated arable land	0	66.24	1,140.05	8.47	0	1,214.76
Complex cultivation patterns	0	6.22	23.95	0	0	30.17
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	120.52	1,392.69	35.93	0	1,549.14
			Gotland			
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	0	83.91	9.41	93.32
Land principally occupied by	0	0	63.13	52.62	0	115.75
Non-irrigated arable land	0	0	538.54	398.49	0	937.03
Complex cultivation patterns	0	0	9.25	10.01	0	19.26
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	0	610.92	545.03	9.41	1,165.36
			Gävleborg			
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	17.35	8.69	0	26.04
Land principally occupied by	0	17.4	48.11	0.05	0	65.56
Non-irrigated arable land	0	294.13	615.24	0.01	0	909.38
Complex cultivation patterns	0	4.55	7.99	0	0	12.54
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	316.08	688.69	8.75	0	1,013.52
			Dalarna			
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**

Pastures	0	0	22.41	7.29	0	29.7
Land principally occupied by	0	35.79	92.24	0	0	128.03
Non-irrigated arable land	0	145.54	584.59	0	0	730.13
Complex cultivation patterns	0	52.39	66.72	0	0	119.11
Fruit trees and berry plantations	0	0	0.3	0	0	0.3
Total	0	233.72	766.26	7.29	0	1007.27
Blekinge						
	Poor	**Moderate**	**Good**	**Very Good**	**Excellent**	**Total**
Pastures	0	0	0.17	30.2	5.66	36.03
Land principally occupied by	0	0	32.82	14.1	0	46.92
Non-irrigated arable land	0	0	119.53	208.96	0	328.49
Complex cultivation patterns	0	0	2.02	0.58	0	2.6
Fruit trees and berry plantations	0	0	0	0	0	0
Total	0	0	154.54	253.84	5.66	414.04

Table A2: The specific electricity production for the capital cities of the investigated counties.

County	**Electricity production for the capital city (kWh/kW$_p$/1st year)**
Västra Götaland	870
Västmanland	940
Västerbotten	916
Västernorrland	892
Värmland	934
Stockholm	927
Uppsala	926
Södermanland	963
Skåne	910
Östergötland	937
Örebro	926
Norrbotten	907
Kronoberg	861
Kalmar	971
Jönköping	927
Jämtland	897
Halland	916
Gotland	1003
Gävleborg	914
Dalarna	895
Blekinge	944

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